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# sunliquid®: Sustainable and Competitive Cellulosic Ethanol from Agricultural Residues

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*Abstract:* The use of lignocellulosic plant material instead of food-based cereals for the production of biobased chemicals and fuels has been a matter of interest for academia and industry over the past years. The crux is the commercial viability of such processes, to be competitive in the fuels and chemicals market. Now, we are at the brink of commercialization with first processes already being implemented worldwide, offering more sustainability, energy security and economic growth.

**Keywords:** Agricultural residues · Biobased chemicals · Biofuel · Cellulosic ethanol · sunliquid® · Sustainability

Today the chemical industry is facing the situation that most of its products are based on fossil resources. Over the last couple of decades the price for oil and fossil derived energy has risen drastically. While a barrel of crude oil was sold at about 20 USD at the end of the last century, today the price is around 100 USD/barrel (with a peak of almost 140 USD/barrel in 2008).[1,2] Thus, the chemical industry is looking for innovations to increase energy and process efficiency as well as to foster the substitution of fossil resources with renewable ones to remain competitive in the long term. Along with this comes an increased demand for more sustainability from the market side. The transition from an entirely fossil fuel-based industry to a more and more bio-based one is one of the mega trends seen in the chemical sector today.

## Sugars – Nature's Building Blocks

Industrial biotechnology is the key enabling technology for the shift towards a sustainable bioeconomy. Today, biobased chemicals and biofuels available in the market are ultimately derived from sugars by means of biotechnological processes. This imposes a new dilemma: Using food or feed for the large-scale production of, for example, fuels and converting land for the production of such feedstock has to be regarded as controversial, as the priority of agriculture is and should be to feed an ever-growing population.

But sugars can not only be derived from foodstuff. The structural, so-called lignocellulosic part of the plants also contains a substantial amount of sugars, bound in long chain sugar polymers cellulose and hemicellulose, glued together by lignin. One hectare of wheat for example yields about 3–3.5 tonnes of sugars bound in lignocellulosic biomass in addition to the 4–4.5 tonnes of sugars from the grain. Hence straw is an extremely attractive additional source of sugars from the non-edible parts of agricultural crops.

These cellulosic sugars are harder but not impossible to access. By using specific enzymes, the stable structure can be efficiently broken down into the corresponding monomeric sugars, which can then be fermented into the desired product. Recent years have seen many advances in research and process development, with cellulosic ethanol being the first product currently on the brink of commercial deployment.

## Cellulosic Ethanol – Advanced Biofuel and Chemical Building Block

The main controversy to date has been the economic viability of such processes. In order to be competitive with ethanol made from conventional sugars, production costs must be comparable. Challenges during the development thus include maximizing yields, reducing enzyme costs (to date still one of the main cost drivers for cellulosic sugar production) and minimizing investment costs while at the same time ensuring a sustainable process with lowest energy demand and highest greenhouse gas savings.

The sunliquid® technology[3] targets all aspects of competitive and sustainable cellulosic ethanol production (Fig. 1). The

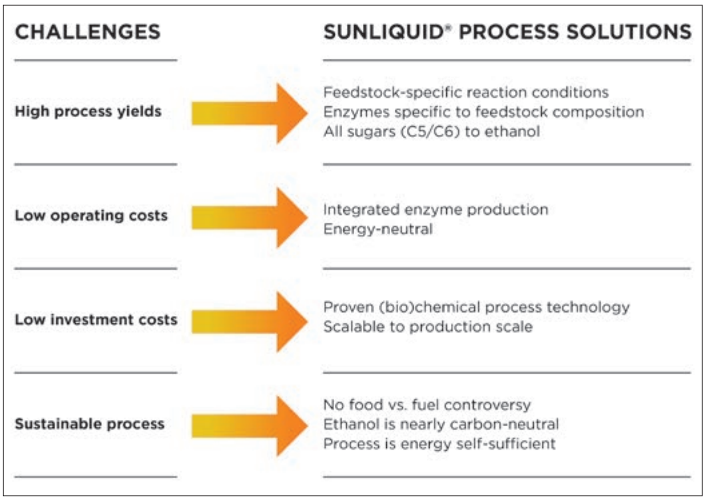


Fig. 1. Process challenges for cellulosic ethanol production and sunliquid® solutions.

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completely integrated process follows four production steps. First, the lignocellulosic biomass is cut into smaller pieces for easier handling, followed by thermal pretreatment with steam under pressure. This will loosen the tight structure of lignin, cellulose and hemicellulose to enhance accessibility for the enzymatic hydrolysis in the next step. To achieve highest sugar yields in the hydrolysis step, Clariant has developed enzyme mixtures specifically tailored for the feedstock and corresponding process conditions in use. Sugar yields exceed those of standard enzyme mixtures.

The enzymes are produced process-integrated. A small proportion of the pretreated feedstock is transferred into a separate production vessel. Highly optimized microorganisms are added, using the feedstock as a nutrient to quickly produce an excess of enzymes. Thus, the enzyme costs are reduced to a minimum, as costs for feedstock, transportation and logistics become negligible (Fig. 2).

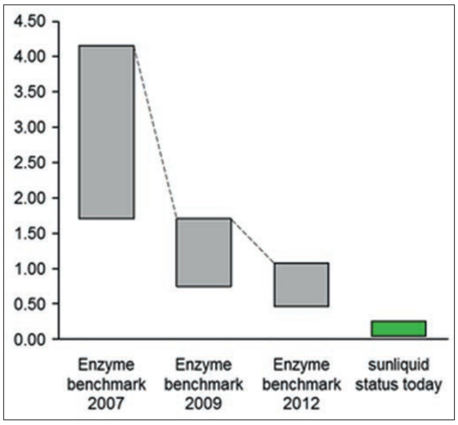


Fig. 2. Enzyme cost comparison [USD/gallon EtOH].

Fig. 3. The sunliquid® demonstration plant in Straubing, Germany.

After hydrolysis, the remaining solid fraction, which is mainly made up of lignin, is separated from the sugar solution. The sugar solution contains both C5 and C6 sugars and both are fermented into ethanol in the next step. For the simultaneous, one-pot conversion of pentoses and hexoses, an optimized fermentation organism has been developed by Clariant as conventional yeast can only digest C6 sugars. Using the additional C5 sugars increases ethanol yield by 50%, further improving economic viability of the process.

In the last process step, the ethanol has to be retrieved from the aqueous solution. Standard process for this procedure is distillation – highly energy intensive as large quantities of water need to be heated together with the desired product. Clariant has developed an innovative and proprietary separation method, based on its know-how in adsorber technology. The water–ethanol solution can thus be concentrated with comparably low energy input, followed by rectification and final treatment to receive anhydrous ethanol, qualifying for use as fuel or chemical. The total ethanol yield lies between 20 and 25% (theoretical maximum: 27%).

Energy demand in this last step can be reduced by up to 50% through this technology, which has a substantial impact on the overall energy balance of the process. The entire process energy necessary to run sunliquid® is derived from the process residues – mainly lignin that is burnt to generate steam and electricity. The plant can run energy self-sufficiently and does not require additional energy input from fossil resources. When calculating the entire life cycle from field to tank, emission savings are 95% compared to fossil fuels.

## On the Brink of Commercialization

Clariant started the development of the sunliquid® technology in 2006. Since 2009 a pilot plant has been operational at the Munich Biotech & Renewables Center. In 2010 the company decided to invest in a demonstration plant, which was officially opened in July 2012. The plant is located in the Lower Bavarian town Straubing and replicates the entire production chain demonstrating the technical feasibility and economic viability of the process (Fig. 3). Annually up to 1,000 tonnes of cellulosic ethanol can be produced in Straubing from about 4,500 tonnes of agricultural residues. Wheat straw was chosen as the first feedstock, since June 2013 also corn stover from North America and sugar cane residues from Brazil have been tested. This is an important milestone in the commercialization of the technology, as it confirms the global potential for this innovative technology.

With the results obtained at the demonstration plant, a first commercial production plant can be planned. The ultimate goal of the company is to license the technology to partners worldwide. The capacity of such a plant will be in the range of 50,000 to 150,000 tonnes of cellulosic ethanol per year converting between 200,000 and 600,000 tonnes of lignocellulosic feedstock. In addition to creating direct and indirect jobs and domestic energy supply, this also offers an additional income opportunity for farmers.

## Feedstock Potential

Lignocellulosic biomass is a by-product of agriculture and accordingly has a huge potential in all regions of the world (Fig. 4).[4] The sunliquid® technology is flexible to the use of different feedstock and can be adjusted to the specific circumstances in each region.

The most important type of agricultural waste in the EU is cereal straw, of which some 240 million tonnes accumulate across the EU's 27 member states each year. Several long-term studies have shown that, depending on the region and prevailing local conditions, up to 60% of the residual straw can be collected from the fields and made available for recycling.[5–7] Using the sunliquid® process, 27 million tonnes of cellulosic ethanol could be produced from this volume of straw, which is equivalent to the energy content of almost 18 million tonnes of fossil fuel-based petrol. This means that around 25% of the EU's demand for gasoline predicted for 2020 could be met by cellulosic ethanol. A study conducted by Bloomberg New Energy Finance includes other types of residue and various scenarios in its calculations and forecasts fossil gasoline substitution potential of up to 62%.[8]

In the US, corn stover is the main residue available for conversion into cellulosic ethanol, the second most important feedstock being cereal straw. The Billion Ton study released by the US Department of Energy estimates the volumes of corn stover and cereal straw available in a sustainable way at 190–290 million tonnes.[9] In Brazil, where sugar cane has already been used to produce bioethanol for many years, some 545 million tonnes of sugar cane are forecast for the 2011–2012 harvest, which will in turn give rise to approx. 73 million tonnes of bagasse.[10] Even after deduction of the amounts used to generate energy in existing plants, around 11 million additional tonnes of cellulosic ethanol could be produced. This is equivalent to about 50% of Brazil' current ethanol production.

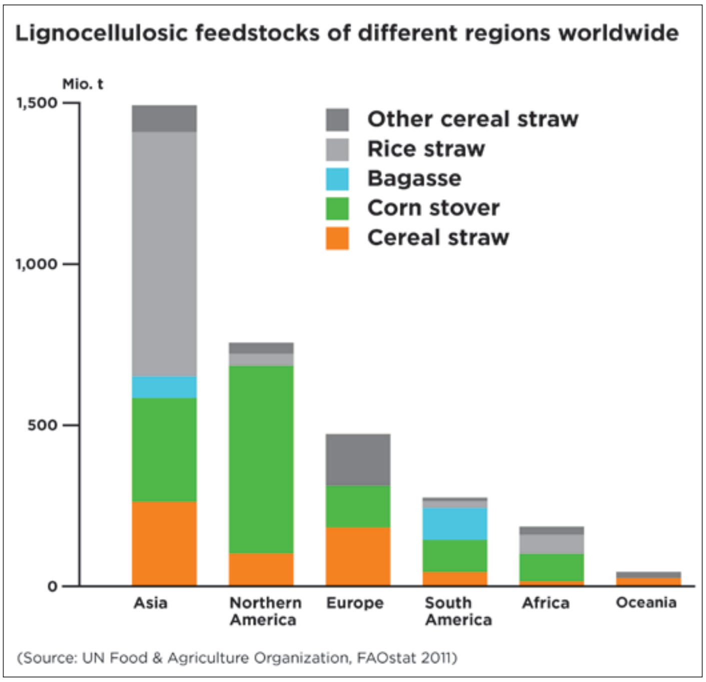


Fig. 4. Availability of different lignocellulosic feedstock in different regions.

## Outlook

Cellulosic ethanol used as biofuel is the first product derived from lignocellulosic biomass entering the market. Ethanol itself has however many other applications and serves as an important feedstock for the chemical industry. In addition, the sunliquid® technology generates access to cellulosic sugars and hence creates a platform for a wide range of biobased chemicals such as organic acids, higher alcohols or other specialty and bulk chemicals.

Commercial deployment of cellulosic ethanol is the next step. This is not a dream of the future, but here today. However, to effectively enter the market, a supportive, reliable framework needs to be in place to foster investment and ensure investors' confidence.

In an economy where resource efficiency and sustainability become more and more important, we need to use all available resources in the most rational way. By using agricultural byproducts for the production of biobased products, both plate and tank can be filled, while at the same time protecting climate and the environment. Furthermore the deployment of such innovative technologies drives economic growth, reduces dependency on fossil resources, creates jobs and diversifies incomes for the agricultural sector.

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